Molecular Mass of a Volatile Liquid

It is often useful to know the molecular mass of a substance. This is one of the properties that helps characterize the substance. If the substance is a volatile liquid, one common way of determining its molecular mass involves using the ideal gas law, $PV = nRT$. Since the liquid is volatile, it can easily be converted to a gas. While it is in the gas phase, its volume, temperature and pressure are measured. The ideal gas law will then allow the calculation of the number of moles of the substance present:

$$n = \frac{PV}{RT}$$

where n is the number of moles of gas, P is pressure, V is volume, R is the ideal gas constant, and T is the temperature on the Kelvin scale. If pressure is given in mmHg, then $R = 62.4$ mmHg•L/mol•K. The number of moles of gas is related to the molecular mass, M, by the expression:

$$n = \frac{\text{grams gas}}{M}$$

The mass of the gas is found by first cooling the gas so that it condenses back into a liquid, and then determining the mass of the condensed liquid. The equations above can be combined into one equation that can be solved directly for molecular mass:

$$M = \frac{\text{grams gas} \times RT}{PV}$$

In this experiment to determine the molecular mass of a volatile liquid, some of the liquid is placed into a small test tube. The test tube is closed with a cork that has a small hole in it. The test tube is heated in boiling water. The liquid vaporizes, the vapors fill the tube and excess vapor leaves through the hole. Since the tube is open to the air, the pressure of the vapor will be the same as the atmospheric pressure. The gas temperature will be that of the boiling water. The volume of the gas, which is the volume of the test tube, can be easily found. The mass of the gas must also be determined. To do this, the test tube is quickly cooled so that the vapor condenses back into a liquid, and the mass of the tube, cork and liquid are found using a sensitive balance.

Preliminary Lab Assignment

1. The following data were obtained in an experiment to find the molecular mass of a liquid:

   Volume of gas: 8.352 mL — Temperature: 99°C
   Pressure: 742 mmHg — Mass of condensed liquid: 0.0326 g

   Calculate the molecular mass of the liquid.

2. The following mistakes were made when carrying out the experiment. What effect does each have on the calculated molecular mass? Be specific. For example, too large because . . .

   a. Only part of the test tube was immersed in the boiling water bath, so the temperature in part of the tube was less than that of the water bath.

   b. One milliliter of the liquid was initially placed in the test tube instead of the recommended 0.5 mL.

   c. The mass of the condensed liquid was not determined quickly. Instead, the test tube was allowed to stand for a while before its mass was measured.

3. List several other methods that can be used to determine molecular mass of unknown substances.

Chemicals

Unknown volatile liquid

Equipment

Test tube, 13- × 100-mm	Beaker, 400-mL
Small cork to fit test tube	Wire test tube holder
Thermometer	Hot plate or Bunsen burner, ring and wire gauze
Ice water bath	Analytical balance
Hammer and nail	Fume hood or funnel attached to an aspirator

Safety Alert

Vapors of the liquids used in this experiment should not be allowed to escape into the room. Work under a hood or under a funnel attached to a water aspirator. The liquid may be flammable or toxic. Check with your teacher to see if it is. If it is flammable, make sure that there are no open flames in the area.

Wear Chemical Splash Goggles and a Chemical-Resistant Apron.

Procedure

Use a nail and hammer to make a small hole in the cork that fits the test tube. Find the mass of the test tube and cork using a sensitive balance.

Pour about 0.5 mL of the unknown volatile liquid into the test tube, insert the cork and immerse the tube in hot water in a large beaker. Use a wire test tube holder to keep the test tube submerged. Don't put the cork on so tightly that the hole is sealed! Keep the cork above the water level. Heat the beaker of water to boiling, and keep at the boiling point while the liquid vaporizes. The expanding vapor will flush the air out of the test tube. As the liquid continues to vaporize, the excess vapor will escape out of the hole in the cork. The vapor will fill the tube at the boiling water temperature and at the room pressure. Keep the test tube in the beaker for at least three minutes after all of the liquid has vaporized. Measure the temperature of the boiling water.

Quickly cool the test tube in an ice bath, dry it off and find the mass of the test tube, cork, and condensed liquid.

Clean the test tube and fill it to the top with water, insert the cork and find the mass of the test tube, water and cork.

Calculate the molecular mass of the volatile liquid.

Record the barometric pressure.

Calculations

Determine the mass of the condensed liquid.

From the mass of the water contained in the test tube and its density, calculate the volume of the test tube.

Use the mass of condensed vapor, pressure, temperature while in the boiling water bath and volume of the test tube to calculate the molecular mass of the liquid.

Discussion

Answer the following questions in your laboratory report:

1. How can the ideal gas law be used to determine the molecular mass of a liquid?
2. Was the vapor really "ideal?" If not, how would this affect the calculated molecular mass? Be specific—for example, too high because . . .
3. Did all of the vapor condense into the liquid? Again, if not, how would this affect the calculated molecular mass?
4. Why is it not necessary to be precise when the liquid is measured out into the test tube?